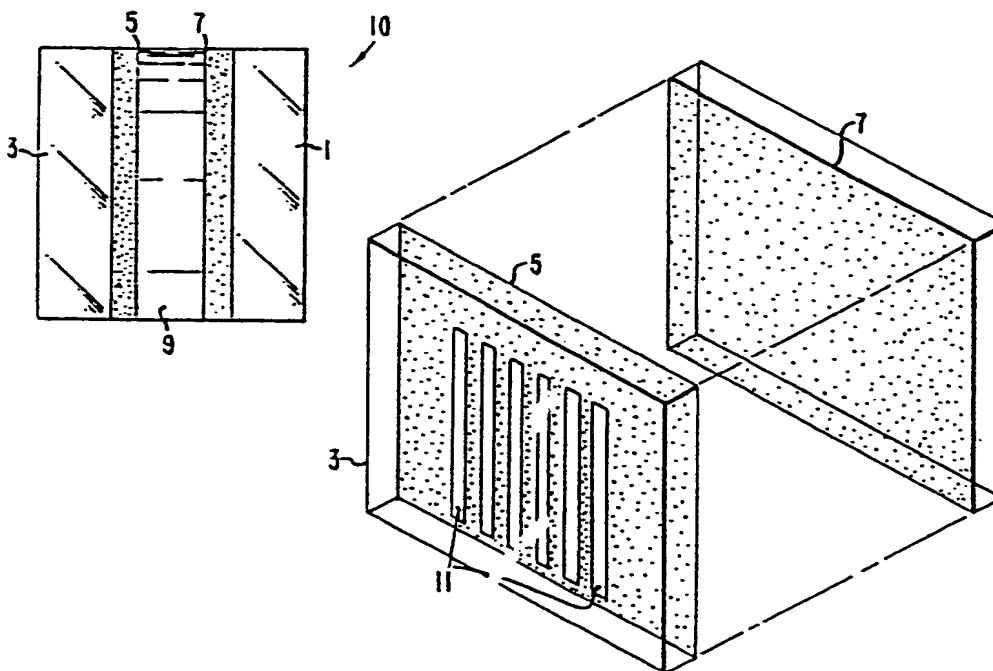




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(54) Title: VOLTAGE TUNABLE OPTICAL BEAM SWITCHING DEVICE



(57) Abstract

A liquid crystal electro-optical switching device utilizing a liquid crystal cell (10) wherein one electrode (5) has a grating pattern (11), and the other electrode is a planar layer. The device acts as a voltage tunable phase grating, whose grating strength is controlled by an external field applied to the electrodes. The switch provides one-dimensional 1 * N splitting with even outputs, and two-dimensional 1 * N switching in a crossed grating configuration.

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-1-

VOLTAGE TUNABLE OPTICAL BEAM SWITCHING DEVICE

1

BACKGROUND OF THE INVENTION1. Field of the Invention

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This invention relates generally to optical information transmission systems and, more particularly, to optical phase gratings and arrangements for optically switching and splitting information utilizing liquid crystal cells.

2. Description of Related Art

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Liquid crystal (LC) cells have been typically used in a wide range of image display applications and more recently have been increasingly used in real-time optical signal processing applications. U.S. Patent No. 4,389,096, Hori et al., "Image Display Apparatus of Liquid Crystal Valve Projection Type", issued on June 21, 1983, discloses a liquid crystal light valve apparatus comprising a liquid crystal layer having dielectric and optical anisotropy which forms part of an electro-optic element, and a Schlieren optical system. An electric field having a spatial intensity distribution corresponding to input image signals is applied to the liquid crystal so that a spatially phase-modulated phase diffraction grating is formed in the liquid crystal layer. The diffracted light forms an enlarged image suitable for projection on a screen. In one of

1 the embodiments disclosed therein, in Col. 5, one of
the electrodes on one of the substrates is constructed
to have a stripe-type electrode structure at a predeter-
mined spatial period. An alternative construction
5 wherein an electric field is applied to the liquid crystal
layer through a high resistance layer of periodical
shape on the electrode attached over the whole surface
of the substrate is also disclosed. A two-dimensional
embodiment uses a light mask and three gratings arranged
10 in different directions as means for forming plural
types of diffraction gratings in the liquid crystal
layer, on the writing light side of the photoconductive
layer. As in other typical image display applications,
the Hori et al. invention uses a photoconductive layer
15 and is directed towards accurately reproducing an
input image. However, optical switch applications
require high efficiency beam control to ensure that
the controllable diffracted orders contain most of the
incident power. For star coupler applications, the
20 transmitted power intensity in the different diffracted
orders must be very nearly equal, with variation being
less than $\pm 10\%$. Thus the variation of the diffracted
intensity of the different orders as a function of the
voltage or wavelength is an important consideration for
25 optical switch applications, a consideration not typically
present in the case of image display applications.

As an example of an LC signal processing application,
see U.S. Patent No. 4,351,589, "Method and Apparatus
for Optical Computing and Logic processing by Mapping
30 of Input Optical Intensity into Position of an Optical
Image" assigned to Hughes Aircraft Company. U.S.
Patent No. 4,351,589 discloses an implementation
utilizing an LC light valve operating in a mode in
which a locally variable phase grating is produced.
35 The variable grating mode (VGM) operation of a liquid

1 crystal device useful for optical processing is discussed
by B.H. Soffer et al. in "Variable Grating Mode Liquid
Crystal Device for Optical Processing," SPIE, Vol. 218,
Devices and Systems for Optical Signal Processing, pp.
5 81-86, 1980. In VGM operation, a variable phase grating
is formed in the liquid crystal cell. The grating
period depends upon the applied voltage and therefore
can be changed by varying the voltage applied to the LC
cell, or in response to an optical signal by adding a
10 photoconductive layer to the cell. In the latter case,
each input signal component will generate a local
grating structure with a particular spatial frequency
which depends on the intensity level of that component.
Thus, in VGM operation, the resultant grating period is
15 neither fixed nor uniform throughout the cell.

The VGM operation of nematic liquid crystals has
been utilized to achieve 1×3 or active splitting devices
as reported by G. L. Tangonan in "Variable-Grating-Mode
Liquid Crystals for Fiber-Optic Applications," Electronics
20 Letters, Vol. 21, No. 16, pp. 701-2, August 1985. The
(*) in " 1×3 " is used in the article to denote one input
port communicating the same signal to 3 output ports,
with each output port receiving equal intensity as
distinguished from the standard nomenclature " $N \times N$ "
25 which is used to denote transmission of N signals from N
input ports to N output ports. The star * denotes
transmission of signals from one input port to N output
ports ($1 \times N$) or N input ports to N output ports ($N \times N$)
with each output port receiving equal intensity. Draw-
30 backs of VGM LC devices for fiber optic applications
include the lack of sufficient efficiency and problems
due to grating imperfections at high fields. Moreover,
reported results indicate that VGM light valves require
dc operating voltages.

35

1 The rapidly developing field of optical communi-
cations and the growing interest in fiber optic communi-
cations has created a need for switches which can
optimally distribute optically transmitted information
5 into different channels. In the past, electrical
switching arrangements have been typically used.
Optical signals are first converted into electric
signals which are switched to new paths. The electric
signals are then used to modulate the output of
10 semiconductor lasers, whereby they are reconverted to
optical signals which are transmitted by the optical
fibers. A major drawback of this type of electrical
switching is that the effective communication bandwidth
is limited.

15 U.S. Patent No. 4,516,837, issued on May 14, 1985
to Soref et al. discloses an "Electro-optical Switch
for Unpolarized Optical Signals" which uses a polarizing
beam splitter cube and a reflector to separate an
arbitrarily polarized incident light beam into polarized
20 components which propagate along parallel paths. A
polarization rotator is positioned in the path of the
reflected component to rotate the plane of polarization
of the light beam component to be coplanar with that of
the undeviated light beam in the parallel path. The two
25 beams are simultaneously or individually deflected by
selectively activating the electrodes of a liquid crystal
nematic reflector/transmitter array confined between
prismatic bodies to emerge at one or more of a plurality
of desired outputs.

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1 As discussed in Col. 8, lines 26-64, the "individual
segmented optically transparent electrodes" are preferably
disposed in two parallel rows, with one optically
transparent electrode in opposition to the individual
5 segmented electrodes, and a single, uniform liquid
crystal film confined between the electrode layers.
This embodiment provides an array of four parallel LC
cells for independent switching of either beam, making
possible eight outputs.

10 Star couplers and bidirectional couplers utilizing
binary phase transmission gratings are discussed by
U. Killat et al. in "Binary Phase Gratings for Couplers
Used in Fiber-Optic Communications," Fiber and Integrated
Optics, Vol. 3, Nos. 2-3, pp. 221-235, 1980. The
15 concepts presented in this article are extended further
by Killat et al. in "Binary Phase Gratings for Star
Couplers with High Splitting Ratio," Fiber and Integrated
Optics, Vol. 4, No. 2, pp. 159-167, 1982. In these
articles, the authors discuss how binary phase trans-
mission gratings exhibiting a certain number of central
20 diffraction orders of equal intensity can be used to
construct one-to-N (that is, $1 \times N$) and N-to-N (that
is, $N \times N$) couplers. These devices are passive phase
grating devices. Passive gratings are suited for use
25 in applications requiring fixed or invariant splitting.
However, with active gratings, the capability of actively
controlling the degree of splitting, which is unavailable
with passive gratings, permits the dynamic reduction
of the number of active star terminals in a data distri-
30 bution network, when the data bus is overloaded.
Therefore active switching devices are particularly
suited for use in data distribution networks.

1 A holographic optical switch which deflects light
beams using a diffraction grating recorded by holographic
means in a light-sensitive crystal, preferably bismuth
5 silicon oxide, to connect two $N \times N$ matrices of optical
fibers, is disclosed in U.S. Patent No. 4,543,662,
entitled "Optical Beam Switching Device and Telephone
Exchange Comprising a Device of This Kind." Although
this optical switch overcomes the bandwidth limitations
10 of the electrical switches because it is holographic
rather than electrical, once the grating is holographi-
cally recorded in the crystal, the device acts as a
passive optical switch. The orientation and spatial
frequency of the grating can thereafter be changed
only by erasing and rewriting the grating. Therefore,
15 erasure of the existing grating and recording of a new
grating will have to be done each time a change in the
switching pattern is desired. This would necessitate
using several lasers for hologram formation, if a
plurality of beams are controlled. Moreover, the
20 holographic switch performs only $N \times N$ switching and,
in a variety of telecommunications, signal processing
and data communications areas, $1 \times N$ switching is
necessary.

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SUMMARY OF THE INVENTION

The present invention provides an LC optical
switch which utilizes an LC cell in which a layer of
liquid crystal material is sandwiched between two plates
of transparent material such as glass. The plates are
30 coated with a transparent conductive electrode layer,
and a grating pattern is formed on one of the plates
of the LC cell. The device acts as a voltage tunable
phase grating, whose grating strength is controlled by
an externally applied field.

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1 An advantage of the present invention is the
provision of an optical switch for $1 * N$ splitting
with even outputs.

5 Another advantage of the present invention is the
utilization of liquid crystal cells to provide one-
dimensional and two-dimensional switching for $1 * N$
coupling of light to fibers.

10 A further advantage of the present invention is
that it achieves the splitting in a single stage.

10 Yet another advantage of the present invention
is the potential for use in active star networks and
power manifoldings.

BRIEF DESCRIPTION OF THE DRAWINGS

15 These and other advantages and features of the
invention will become more fully apparent from the
following detailed description and the accompanying
drawings wherein like referenced characters refer to
like parts throughout and in which:

20 FIG. 1a is a sectional view of the LC cell
of the present invention;

 FIG. 1b is an exploded perspective view of
component parts of the cell shown in FIG. 1a;

25 FIG. 1c is a schematic diagram of the switching
arrangement of the present invention;

 FIGS. 2-5 show the various diffraction orders
resulting when different operating voltages are applied
to the device of the present invention;

30 FIG. 6a is a schematic diagram of the
arrangement for two-dimensional switching utilizing the
present invention; and

 FIG. 6b is a display resulting from the two-
dimensional switching achieved using the arrangement
shown in FIG. 6a.

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1 DESCRIPTION OF THE PREFERRED EMBODIMENTS

 FIG. 1a is a sectional view showing the basic
structure of the LC cell 10 of the present invention. Two
transparent, smooth plates 1 and 3, of a material
5 such as glass, preferably with a thickness of the order
of 1 mm, are coated with a transparent, conductive
material such as indium tin oxide (ITO) to provide
conductive electrode surfaces 5 and 7. Homogeneous
alignment of the liquid crystal molecules in the
10 quiescent state is induced by conventional methods such
as rubbing or ion bombardment etch-alignment. In a
homogeneously aligned LC, the quiescent state alignment
is parallel to the boundary surface. The LC material 9
is sandwiched in a thin layer, as is typically done,
15 between plates 1 and 3. Liquid crystal layers of
thickness on the order of 6 μm are used in conventional
cells to provide efficient electro-optic modulation and
reasonably low drive voltages ($<10\text{ V}$).

 A grating pattern, as shown in FIG. 1b, is then
20 formed in ITO layer 5 by photolithographically forming
a mask thereon and then removing the unmasked ITO
portions using conventional ion beam sputtering. Other
suitable conventional techniques can be used to form
the grating pattern. The electrode 5 of the present
25 invention is thus arranged in a typical grating pattern
11, as a series of parallel lines of uniform and
identical widths with uniform spacing or gaps between
them. The width of the grating lines and the grating
period selected will depend on individual system require-
30 ments and the following generally applicable design
consideration. The thicker the LC layer, the lower is
the operating voltage required. Additionally, if the
lines 11 are made extremely narrow (for example, 5 μm)

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1 and the gaps between them of equal width or greater,
the effect of the electrical field they exert may
result only in insufficient local rearrangement of the
molecular alignment in an LC layer 9 on the order of
5 6-12 μm thick. However, if the lines are, for example,
25 μm wide and the gaps between them are of equal or
greater width, the effect of the electric fields exerted
by the relatively wider electrode lines will be more
efficiently localized, resulting in rearrangement of
10 molecular alignment over a larger area. Hence, the
design considerations of voltage magnitude, electric
field efficiency, area of domains wherein rearrangement
of molecular alignment occurs, and the tradeoff between
operating voltage and electric field efficiency in
15 effecting molecular orientation, will influence the
determination of the dimensions of the grating pattern
in which the electrodes are arranged.

The LC cell 10 of the present invention can be made
by any of the techniques commonly used in the liquid
20 crystal electro-optic device art. The primary difference
between the LC cell 10 of the present invention and the
prior electro-optic liquid crystalline devices is the
patterning of the electrode structure to provide a
voltage-tunable phase grating suitable for electro-
25 optic switching. Any suitable nematic liquid crystalline
material can be used as LC layer 9. Since the bire-
fringence, B , of the liquid crystal can be very large,
for example $B = 0.2$, and the LC cell thickness is
typically, as indicated earlier, less than 12 μm ,
30 strong electrooptic interactions occur even at low
operating voltages. The LC cell described above is
driven by conventional external circuitry in a known
manner.

1 An LC cell in accordance with the present invention
was constructed for test purposes. Referring to FIG. 1a,
the experimental cell 10 was constructed using two glass
plates 1 and 3, each 3 mm thick, and each coated with
5 700Å thick transparent and conductive ITO layers 5 and 7.
After rubbing the coated glass plates 1 and 3 to uniformly
and homogeneously align the liquid crystal molecules, a
12 µm thick layer of a commercially available nematic
LC mixture (BDH E7), supplied by BDH Chemicals, Ltd.
10 Poole, Dorset, England, was sandwiched between the two
glass plates 1 and 3 which were separated by a Mylar
spacer. Patterning of ITO layer 5 was then accomplished
by photolithographically forming a mask thereon, and
removing the ITO left exposed by the mask using ion
15 beam sputtering. A grating pattern 11 with lines 25
µm wide with 25 µm spacing between them was formed.

 The orientation of the LC molecules was such that
the optic axis, also referred to as the director, L, of
the liquid crystal was parallel to the grating lines 11.
20 The LC cell 10 was tested at HeNe (0.63 µm) and GaAlAs
(0.82 µm) wavelengths using the arrangement shown in
FIG. 1c. Polarization orientation of input light with
respect to the grating lines was adjusted to obtain an
even 1 * 5 split at a certain voltage for each wavelength.
25 Initially, with the applied voltage, $V = 0$, the LC
molecules are homogeneously aligned parallel to the L
direction, that is, the boundary surface. The applied
voltage was typically a 10 KHz ac signal with a 0 to 20 V
range.

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1 No analyzer was used at the output. Instead, to
facilitate voltage adjustment, viewing and quantitative
measurement, light transmitted by the LC cell 10 was
focussed on a conventional reticon. The reticon output
5 was displayed on an oscilloscope. This arrangement
permitted observation of $1 * N$ splitting and the
voltage dependence of diffraction orders.

Referring now to FIG. 2, the oscilloscope display
of the transmitted light output for an operating voltage
10 of 3.5 V shows that the maximum intensity transmitted
corresponds to the zero order and a weak tap state on
the order of 0.9 dB exists at the two first orders on
either side of the zero order.

The oscilloscope display of the light transmitted
15 for an operating voltage of 4.0 V is shown in FIG. 3.
Three maxima are clearly visible corresponding to the
zero and first orders, with weak tap states in the
second orders. The intensity of the diffracted light
is thereby almost entirely confined to these three
20 maxima and thus $1 * 3$ power splitting is achieved with
loss on the order of 1 dB.

As can be seen from FIG. 4, for an operating
voltage of 4.2 V, five maxima are clearly visible
corresponding to the zero, first and second orders,
25 with weak tap states at the third orders. Thus, $1 * 5$
splitting is achieved with loss on the order of only
0.7 dB or less.

The loss figures given above include the loss to
the unwanted orders.

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1 The experimental observations indicate that the
splitting efficiency is high since the overall loss
figure is only on the order of 1 dB and the LC grating
generates diffraction orders of equal intensity. The
5 latter is visually evident in FIGS. 3 and 4. The spread
in output intensities was observed to be on the order
of 1/50. Cell transmission is typically > 95%, neglecting
reflections.

 In the arrangement whose output is illustrated in
10 FIG. 3, the LC cell 10 of the present invention generates
 $N = 2$ diffraction orders for each of the light beams
originating from one input port. Therefore, $2N - 1$ or
3 output ports will be necessary to collect all of
these light beams. Similarly, corresponding to FIG. 4,
15 wherein $N = 3$, five output ports will be necessary to
collect the light transmitted by LC cell 10.

 Referring to FIG. 5, it can be seen that for an
operating voltage of 4.75 V, there are first order
nulls and weak tap states in the second, third and
20 fourth orders.

 In other cells, with different degrees of LC
alignment 1×7 splitting was observed with $\pm 20\%$
variation in the output intensities.

 It is to be understood that without departing
25 from the spirit of the invention in using a grating
electrode pattern, actual dimensions of the LC cell and
the grating pattern, polarization orientation of input
light, and output collection means can be varied in
alternative embodiments. The experimental observations
30 discussed herein are made by way of illustration only
and not of limitation.

1 Couplers with higher splitting factors than those
discussed above can be obtained by crossing two gratings
at an angle. The concept of two-dimensional switching
using crossed gratings is known. See, for example, the
5 earlier-referenced article by Killat et al, "Binary
Phase Gratings for Star Couplers with High Splitting
Ratio," pp. 163-7. Killat et al. report results
obtained by crossing two gratings at an angle of 60 or
90 degrees. They were able to achieve a 1×35 coupler
10 with an overall loss on the order of 2.3 dB using
graded index fibers with 50 μm core diameter, which
to their knowledge was the highest splitting ratio
achieved at that time.

The two-dimensional switching embodiment for
15 the present invention is illustrated in FIG. 6a.
A conventional binary phase grating 12, such as that
described by Killat et al. or other suitable phase
gratings is crossed at an angle, preferably 60° or 90°
relative to the voltage tunable phase grating LC cell
20 10 of the present invention. Without any voltage being
applied to LC cell 10, only the binary phase grating 12
will perform passive switching. When a suitable voltage
is applied to LC cell 10, the active grating is activated
and two-dimensional splitting with a high splitting
25 ratio is achieved, thereby permitting active addressing
of a large number of output ports. For example, passive
 1×3 splitting was achieved using a conventionally
fabricated binary phase grating formed by etching a
glass slide. The splitting was achieved by controlling
30 the etch time until a suitable phase shift of $\phi = 2$ rad
was attained, which is known to correspond to a splitting
ratio of 1×3 . The voltage tunable phase grating
10 of the present invention, adjusted to perform 1×7

1 splitting, was oriented at an angle of 90 degrees
relative to the passive grating 12. It was found that
an operating voltage of 8V optimally resulted in 1 * 7
splitting with 1.5 dB intensity uniformity. It was also
5 observed that devices of the present invention perform
1 * 7 splitting with less uniformity in output intensities
than corresponding devices performing 1 * 3 or 1 * 5
splitting. When the voltage controlled phase grating
10 10 was operated at 4V, the 3 output spots generated by
the passive grating 12 were transformed to a two-
dimensional 3 x 7 pattern, as shown in FIG. 6b. In
effect, therefore a conversion of 1 * 3 splitting to
1 * 21 splitting was achieved. In this embodiment, a
two-dimensional output fiber array can effectively be
15 addressed by the combination of active and passive
gratings. Note that different output states can be
achieved by altering the voltage settings of the phase
gratings 12 and 10, by altering the angle at which
the gratings are crossed, by altering the splitting
20 characteristics of the passive grating 12 used in this
embodiment and by suitably varying the operating
characteristics of LC cell 10.

In yet another embodiment, two dimensional
splitting can be performed with two crossed gratings,
25 both active, in essentially the same arrangement as
discussed above.

The specific embodiments of the present invention
shown and described herein are merely illustrative.
Many modifications and variations of the present
30 invention are possible in light of the above teachings
and may be made therein without departing from the
spirit and scope of the invention as set forth in the
appended claims.

CLAIMSWhat is Claimed is:

- 1 1. A voltage-tunable optical beam switching
device comprising:
 a liquid crystal cell having transparent
electrodes arranged in a grating pattern and forming a
5 voltage-tunable phase grating; and
 voltage applying means connected to said
liquid crystal cell for applying different voltages to
said liquid crystal cell through said electrodes,
 whereby an input optical beam from an input port
10 is switched to at least one output port after passage
through said voltage-tunable phase grating.
- 1 2. A device according to Claim 1 in which said
liquid crystal cell comprises:
 two plates of flat, transparent material;
 liquid crystal material sandwiched between
5 said plates;
 said plates being coated with a transparent,
conductive electrode material; and
 wherein said conductive coatings on said plates
are suitably processed to form transparent electrodes
10 arranged in a grating pattern.
- 1 3. A device according to Claim 2 wherein said
plates are made of glass.
- 1 4. A device according to Claim 2 wherein said
liquid crystal is nematic.
- 1 5. A device according to Claim 2 wherein said
transparent conductive coating is a composite oxide of
indium and tin.

1 6. A device according to Claim 1 further
including a display means connected to said liquid
crystal cell for displaying the distribution of intensity
amongst the diffracted orders resulting from an input
5 beam passing through said voltage-tunable phase grating.

1 7. A device according to Claim 1 wherein said
input port is an optical fiber.

1 8. A device according to Claim 1 wherein said
at least one output port is at least one optical fiber.

1 9. An active optical switching arrangement for
optically connecting one input port to a plurality of
output ports comprising:
a liquid crystal cell having transparent
5 electrodes arranged in a grating pattern;
means for inputting light of suitable
polarization at a suitable angle with respect to
the orientation of said grating pattern;
means for applying a variable voltage to
10 said electrodes; and
means at said output ports for receiving the
output of said liquid crystal cell.

1 10. An arrangement according to Claim 9 further
including a display means connected to said liquid
crystal cell at said output port.

1 11. A device according to Claim 9 wherein said
input and output ports are optical fibers.

1 12. A two-dimensional voltage-tunable optical
beam switching device comprising:
 a binary phase grating;
 said grating being crossed at an angle with
5 respect to the optic axis of a liquid crystal cell;
 said liquid crystal cell having transparent
electrodes arranged in a grating pattern; and
 voltage applying means connected to said
liquid crystal cell for applying variable voltages to
10 said liquid crystal cell through said electrodes, so
as to form a voltage-tunable phase grating,
 whereby an optical beam from an input port is
deflected in two dimensions by said crossed phase
gratings, enabling optical connection of an input port
15 with a plurality of output ports.

1 13. A two-dimensional voltage-tunable optical
beam switching device comprising at least two liquid
crystal cells;
 said cells having transparent electrodes
5 arranged in a grating pattern and voltage applying
means for applying variable voltages through said
electrodes, thereby forming voltage-tunable phase
gratings;
 said at least two voltage-tunable phase
10 gratings being crossed such that the optic axis of each
is at an angle to the other,
 whereby an optical beam from an input port is
deflected in two dimensions by said crossed phase
gratings, enabling optical connection of an input port
15 with a plurality of output ports.

- 1 14. A multi-dimensional voltage-tunable optical beam switching device according to Claim 1, comprising at least two said liquid crystal cells in a crossed configuration.

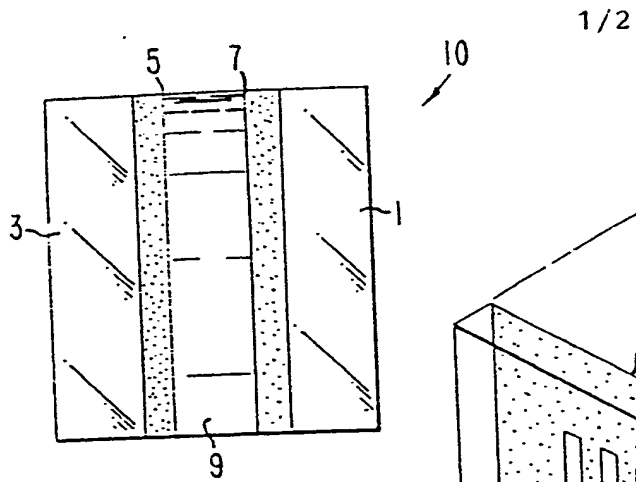


Fig. 1a.

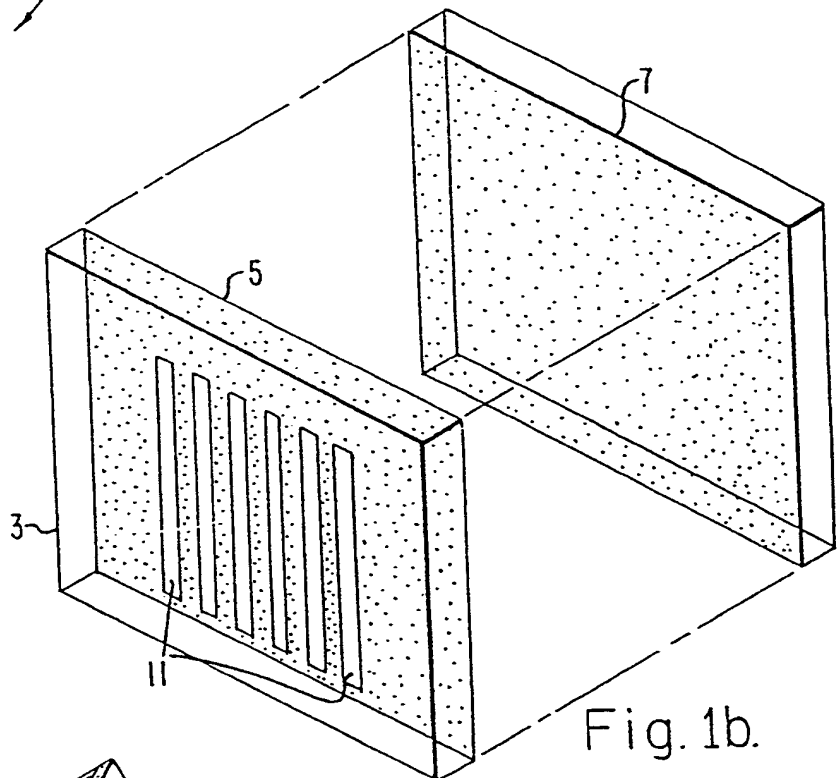


Fig. 1b.

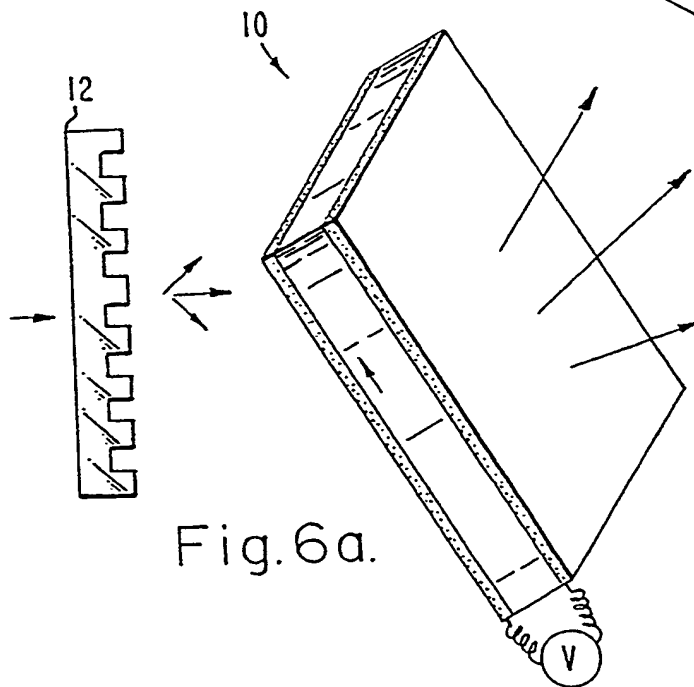


Fig. 6a.

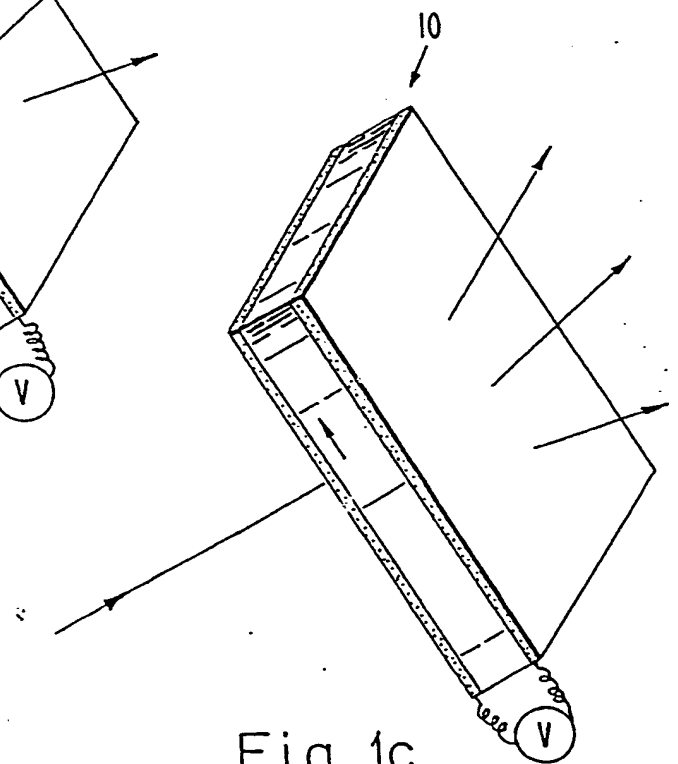


Fig. 1c.

2/2

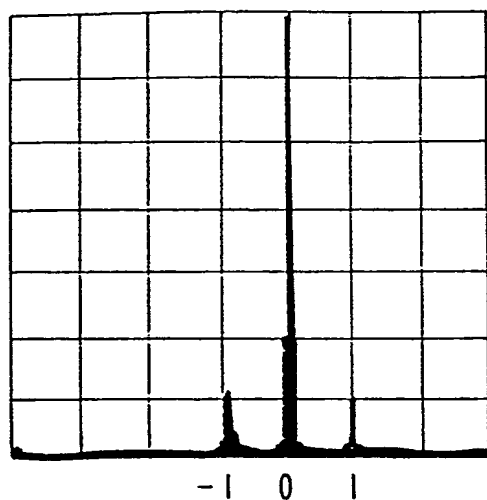


Fig. 2.

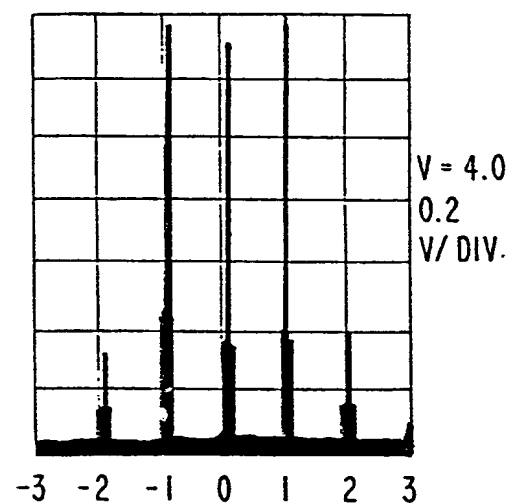


Fig. 3.

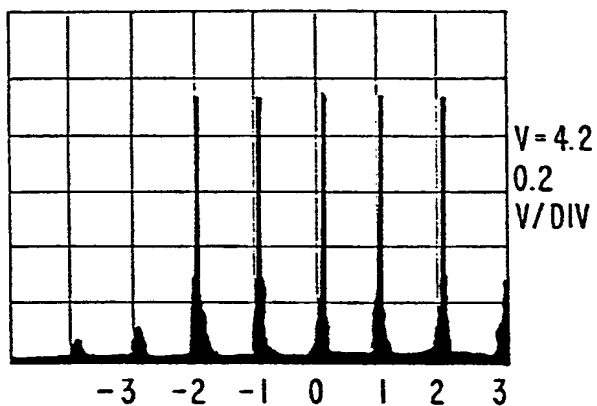


Fig. 4.

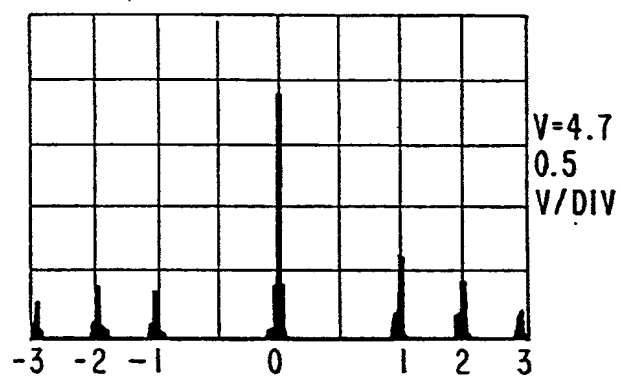


Fig. 5.

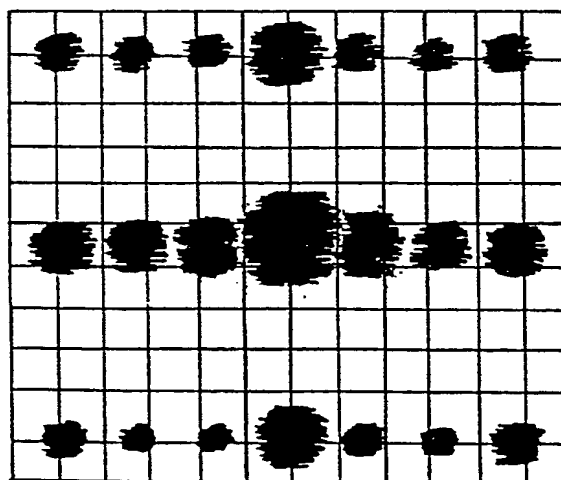


Fig. 6b.

INTERNATIONAL SEARCH REPORT

International Application No PCT/US 87/00105

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) ⁶ According to International Patent Classification (IPC) or to both National Classification and IPC IPC ⁴ : G 02 F 1/29																				
II. FIELDS SEARCHED <div style="text-align: center; margin-top: 10px;">Minimum Documentation Searched ⁷</div> <table style="width: 100%; border: none;"> <tr> <td style="width: 25%; border-bottom: 1px solid black; padding-bottom: 5px;">Classification System</td> <td style="border-bottom: 1px solid black; padding-bottom: 5px;">Classification Symbols</td> </tr> <tr> <td style="padding: 5px;">IPC⁴</td> <td style="padding: 5px;">G 02 F</td> </tr> </table> <div style="text-align: center; margin-top: 10px; font-size: small;">Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched ⁸</div>			Classification System	Classification Symbols	IPC ⁴	G 02 F														
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III. DOCUMENTS CONSIDERED TO BE RELEVANT ⁹ <table border="1" style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th style="width: 10%; padding: 5px;">Category ⁹</th> <th style="width: 70%; padding: 5px;">Citation of Document, ¹¹ with indication, where appropriate, of the relevant passages ¹²</th> <th style="width: 20%; padding: 5px;">Relevant to Claim No. ¹³</th> </tr> </thead> <tbody> <tr> <td style="text-align: center; vertical-align: top; padding: 5px;">X</td> <td style="padding: 5px;">FR, A, 2254057 (THOMSON-CSF) 4 July 1975, see figures 3,5; page 1, lines 1-4,27 - page 2, line 1; page 4, line 16 - page 6, line 1; page 6, line 28 - page 7, line 27</td> <td style="text-align: center; vertical-align: top; padding: 5px;">1-4,13,14</td> </tr> <tr> <td style="text-align: center; vertical-align: top; padding: 5px;">Y</td> <td style="text-align: center; vertical-align: top; padding: 5px;">--</td> <td style="text-align: center; vertical-align: top; padding: 5px;">7-9,11</td> </tr> <tr> <td style="text-align: center; vertical-align: top; padding: 5px;">A</td> <td></td> <td style="text-align: center; vertical-align: top; padding: 5px;">12</td> </tr> <tr> <td style="text-align: center; vertical-align: top; padding: 5px;">Y</td> <td style="padding: 5px;">EP, A, 0074144 (N.V. PHILIPS') 16 March 1983, see page 1, lines 1-12; figure 1; page 2, line 32 - page 3, line 10</td> <td style="text-align: center; vertical-align: top; padding: 5px;">7-9,11</td> </tr> <tr> <td style="text-align: center; vertical-align: top; padding: 5px;">X</td> <td style="padding: 5px;">IEEE Transactions on Electron Devices, vol. ED-26, no. 11, November 1979 (IEEE, New York, USA), Yoshikazu et al., "Field controllable liquid crystal phase grating", pages 1734-1737, see the whole article -----</td> <td style="text-align: center; vertical-align: top; padding: 5px;">1-5</td> </tr> </tbody> </table>			Category ⁹	Citation of Document, ¹¹ with indication, where appropriate, of the relevant passages ¹²	Relevant to Claim No. ¹³	X	FR, A, 2254057 (THOMSON-CSF) 4 July 1975, see figures 3,5; page 1, lines 1-4,27 - page 2, line 1; page 4, line 16 - page 6, line 1; page 6, line 28 - page 7, line 27	1-4,13,14	Y	--	7-9,11	A		12	Y	EP, A, 0074144 (N.V. PHILIPS') 16 March 1983, see page 1, lines 1-12; figure 1; page 2, line 32 - page 3, line 10	7-9,11	X	IEEE Transactions on Electron Devices, vol. ED-26, no. 11, November 1979 (IEEE, New York, USA), Yoshikazu et al., "Field controllable liquid crystal phase grating", pages 1734-1737, see the whole article -----	1-5
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<div style="display: flex; justify-content: space-between;"> <div style="width: 45%;"> <p>¹⁰ Special categories of cited documents:</p> <p>"A" document defining the general state of the art which is not considered to be of particular relevance</p> <p>"E" earlier document but published on or after the international filing date</p> <p>"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)</p> <p>"O" document referring to an oral disclosure, use, exhibition or other means</p> <p>"P" document published prior to the international filing date but later than the priority date claimed</p> </div> <div style="width: 45%;"> <p>"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention</p> <p>"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step</p> <p>"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.</p> <p>"d" document member of the same patent family</p> </div> </div>																				
IV. CERTIFICATION <table style="width: 100%; border: none;"> <tr> <td style="width: 50%; border-bottom: 1px solid black; padding-bottom: 5px;">Date of the Actual Completion of the International Search</td> <td style="width: 50%; border-bottom: 1px solid black; padding-bottom: 5px;">Date of Mailing of this International Search Report</td> </tr> <tr> <td style="padding: 5px;">7th May 1987</td> <td style="text-align: center; padding: 5px;">09 JUN 1987</td> </tr> <tr> <td style="border-bottom: 1px solid black; padding-bottom: 5px;">International Searching Authority</td> <td style="border-bottom: 1px solid black; padding-bottom: 5px;">Signature of Authorized Officer</td> </tr> <tr> <td style="text-align: center; padding: 5px;">EUROPEAN PATENT OFFICE</td> <td style="padding: 5px;">M. VAN MOL </td> </tr> </table>			Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report	7th May 1987	09 JUN 1987	International Searching Authority	Signature of Authorized Officer	EUROPEAN PATENT OFFICE	M. VAN MOL										
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ANNEX TO THE INTERNATIONAL SEARCH REPORT ON

INTERNATIONAL APPLICATION NO.

PCT/US 87/00105 (SA 16018)

This Annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report. The members are as contained in the European Patent Office EDP file on 25/05/87

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Patent document cited in search report	Publication date	Patent family member(s)	Publication date
FR-A- 2254057	04/07/75	None	
EP-A- 0074144	16/03/83	JP-A- 58054322	31/03/83
		NL-A- 8104122	05/04/83
		CA-A- 1180095	25/12/84

For more details about this annex :
see Official Journal of the European Patent Office, No. 12/82